INDIA'S GUIDE TO DEVELOPING COUNTRIES

Indian experience and study may be valuable in assisting developing countries to assess the benefits possible from wise application of nuclear energy. At the Twelfth Session of the General Conference Dr Vikram Sarabhai, Chairman of the Atomic Energy Commission of India, gave a special lecture illustrating uses to be made of low cost energy from nuclear sources.

This article is a shortened version of the lecture which was prepared in collaboration with V.N. Meckoni and K.T. Thomas . Dr. Sarabhai said:

I wish to share with you some results of our studies to identify the relevance and scope of nuclear power in India and of experiences we have acquired in attempting to satisfy the rapidly growing demand for nuclear power.

I wish firstly, to illustrate the methodology of quantitative analysis which is required and secondly, to describe the results which indeed indicate that the potential benefits of low cost energy sources now available through nuclear power are capable of inducing a major transformation in a large community.

There are four major regional grids in India, each with an installed capacity of about 3000 MW electrical and a maximum demand which is about two-thirds of the installed capacity. The doubling time of consumption is about five years which means that currently about 400 to 500 MW additional generating capacity is required annually in each grid. Hydroelectric power has played a significant role (30 to 50% of the total) and will continue to do so in the future. It has, however, some rather special characteristics which derive from the seasonal character of rainfall during the Indian monsoon. Whether it is from direct rainfall or from the melting snows in the Himalayas, the water in our hydro-electric reservoirs gets replenished largely on a seasonal basis. The average load during the year is in consequence only 30 to 50% of the installed capacity. Moreover, the variance of rainfall in different regions in India is generally largest where the annual rainfall itself is not plentiful. There are many regions where an already marginal economy is thrown seriously out of gear every few years by drought and power cuts.

Another feature of the load in our grids is the large range of variations. In the northern grid we have a peak load of 1430 MW, but the minimum load is 600 MW. For about fifty percent of the time the load is less than one-third of the installed capacity. This illustrates the vast scope for economy of capital expenditure and of reducing the cost of power through an improvement of the load factor. Where the utilisation of installed capacity is small due to large seasonal changes in the supply of reservoir water, pumped storage based on low cost thermal or atomic power from a base load station can be advantageously used. Where the unsatisfactory nature of the load factor curve is due to users who do not provide continuous load at all times of the day or in different seasons, the extra power can be costed inexpensively on an incremental basis and used for a number of processes which depend on low cost electrical energy.

WHY POWER COSTS ARE HIGH

A factor that continually hampers the progress of a developing region is the small base from which it starts to build its economy. Even with a large rate of growth, the incremental generating capacity required is small and results in the acquisition of single units of small size. In the next three years the largest number of hydro-electric or thermal generating plants to be commissioned would be of sizes ranging from 50 to 100 MW. Indeed the three nuclear plants that are now being established are the only ones with large single units of 200 MW each. It is not surprising that with this situation we end up with power costs ranging from 9 to 12 mills per kW hour, which is about twice as expensive as power used by industrially advanced nations.

The economic implications of this state of affairs are very clearly brought out in figure 1 where the capital costs and the unit generating costs of coal and nuclear power stations ranging in capacity from 200 to 1000 MW have been estimated. The reactor considered is of the heavy water moderated heavy water cooled type using natural uranium. We have projected the cost on the basis of experience under Indian conditions of building Candu Reactors. Under our conditions today a 500 MW Candu Reactor is expected to have a unit generating cost fully competitive with a thermal unit of equivalent size erected at the pit-head providing lowest cost coal. When the price of coal is 13 cents per million BTU, as it is in some other countries, the break even point in unit generating cost occurs not at 500 MW size but at about 800 to 900 MW. It will be noticed that within the range considered, the capital cost of the Candu Reactor is from 80 to 40% more than the capital cost of an equivalent thermal power station. The additional capital cost, which includes a heavy water inventory, may make a significant difference to the choice of the reactor in some countries. But balanced against this would be the foreign exchange cost and dependence on external source of fuel if the Boiling or Pressurized light water reactor of lower capital cost is considered, using enriched fuel.

Figure 2 takes into account the major coal deposits currently exploited, and the transportation cost by rail from pithead to the generating station. It indicates regions where thermal power stations would still be more economical than nuclear. It will be observed that the contour for a 200 MW Candu unit clears Tarapur on the West coast, Rajasthan and Madras where India's first three nuclear power stations with a total capacity of 1000 MW are currently under construction. Through fortunate coincidence the doubling time of grids requires new capacity of 400 to 500 MW per year. Thus there is today in India the potential for the establishment of 500 MW nuclear stations

PROJECTED COSTS FOR COAL FIRED THERMAL STATIONS AND CANDU TYPE REACTORS IN INDIA

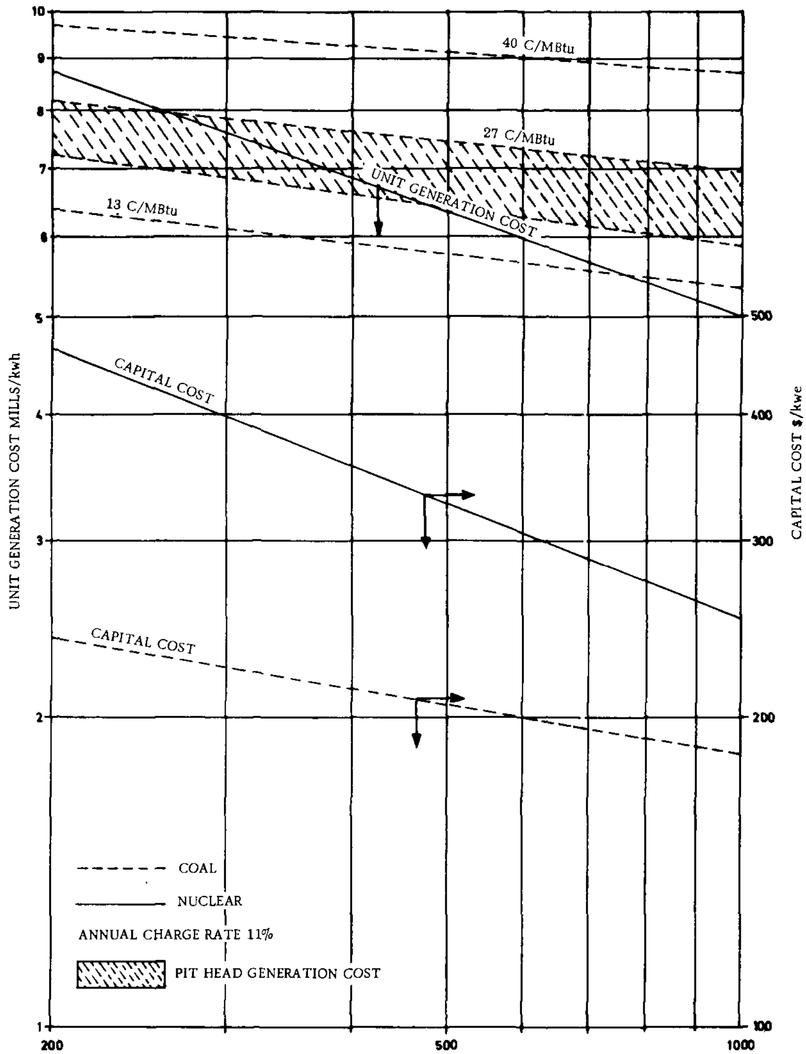

Fig. 1

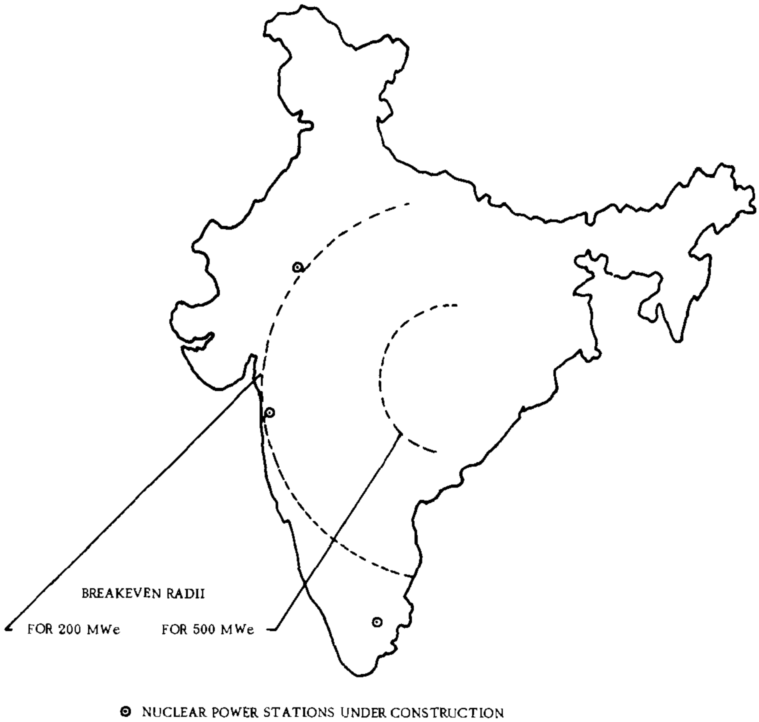
BREAKEVEN RADII
FOR 200 MWe
FOR 500 MWe
NUCLEAR POWER STATIONS UNDER CONSTRUCTION

Fig. 2

in several areas of the country, provided appropriate transmission lines and interconnections between grids are available.

MAKING FULL USE OF NUCLEAR POWER

The economic advantage of nuclear power can be realised only if one can ensure a guaranteed base load of about 80 to 85%. A number of electro-chemical processes and desalination of water and the use of electricity for pumping water from tube-wells have been examined to ascertain whether by a careful choice of energy consuming projects related to a low-cost energy producing centre, one could provide not only fresh inputs for economic development, but a balanced load within the grid systems.

A study team was constituted by the Indian Atomic Energy Commission at the end of last year in order to study the impact of relevant technological developments on the pattern of industry and agriculture in India. It had the benefit of the studies made at the Oak Ridge National Laboratory of the U.S. Atomic Energy Commission. The cost of production of nitrogen and phosphatic fertilisers under Indian conditions by conventional processes have been compared against alternative electrolytic or electrothermic processes.

At a power cost of 3.5 mills/kwh a fertiliser plant based on coal located at a distance upto 800 Kms from the pit head (price of coal at the plant site Rs. 58/tonne) would be more economical than a plant using electrolysis. With the present indigenous price of Rs. 90/-for LSHS and Rs. 110/- for naphtha, the electrolytic plant will be able to compete only if the cost of electricity is reduced to 2 mills/kwh. However, in India the availability of naphtha is dependent on the refining capacity installed for other petroleum products like gasolene diesel, etc., with much of the crude required for the purpose being imported.

In a comparison of the electric furnace for phosphorus against the wet process at a power cost of 3.5 mills/kwh, the break-even point for both triple super-phosphate and diammonium phosphate is at a sulphur price (for the wet process) of about Rs. 575/Te. The price of sulphur in India had been of that order in 1967. Now it is slightly less (Rs. 450-500 tonne).

In an aluminium plant with a capacity of 50 000 tonnes a year, the production cost of fabricated aluminium at a power cost of 3.5 mills/kwh is approximately Rs. 3400/-per tonne. The present ex-factory sale price of fabricated aluminium in India is approximately Rs. 5, 500/Te.

ECONOMICS OF DESALTED WATER

The cost of power from a single purpose nuclear power plant of 2 × 600 MWe has been estimated to be 3.5 mills/kwh. Assuming a power credit of this value, estimates of the cost of water from dual purpose plants producing 100 - 500 million gallons a day have been made.

In order to assess the profitability of using desalted water for agriculture the cost of water and its relation to agricultural income has been studied for a coastal arid region. Unlike water from a conventional source like monsoon, desalted water will be available throughout the year. Also it is necessary to maintain a high load factor as desalting is a capital intensive industry. These features of the desalting industry, dictate uniform use of the water through all seasons, which makes multiple cropping important for sound economics.

The influence of the cost of water on certain crop rotations, viz. hybrid maize-potato-summer ground-nut and hybrid maize-wheat-summer groundnut have been studied for regions like Gujarat in India.

Figure 3 gives the net profit per hectare at varying water cost. By net profit is meant the return from the sale of the produce less all costs for cultivation. Here crop rotation No. 1 is profitable upto 53 cents (4 rupees) per 1000 gallons and No. 2 is profitable upto 37 cents (Rs. 2.80) per 1000 gallons. It has been estimated that the cost of water from a 150 MGD desalination plant including distribution cost would be about Rs. 3 or 40 cents per 1000 gallons. At this price the family income would be about Rs. 9, 750/ hectare: ($1300/hectare) for rotation 1 and about Rs. 2, 500/hectare ($333/ hectare) for rotation No. 2. The respective figures for 'net profit' are Rs. 4, 750 ($633) and a loss of Rs. 500 ($67). Hence it can be seen that by using desalted water crop rotation No. 1 would give a reasonable return.

The detailed implications of this concept have been evaluated for a region of Western Uttar Pradesh, with a population of 22.5 million people. It has Delhi to the West, Agra to the South and the Ganges flowing through its middle. There is a large amount of underground water and the soil is mostly alluvial in character. A suggested installation involves a power station with two nuclear reactors each of 600 MWe capacity. A fertilizer plant of capacity of 4, 500 tonnes per day and an aluminium plant of 150 tonnes per day is envisaged with approximately 200 MWe used for lift irrigation through 36, 000 tube wells.

Table 1 shows that the total investment is about Rs. 429 crores ($570 millions). Table 2 shows that the return on this investment is expected to be about 14%. In arriving at this evaluation differential tariff rates of 2.7 mills/kwh for fertilisers and 3.5 mills/kwh for aluminium and 13 mills/ kwh for tubewells have been assumed. Though the power cost for the tubewells has been taken high, the agricultural project gives sufficiently high returns. A summary of the salient features of the agricultural part of the project is given in table 3. Approximately 720 000 hectares are proposed to be irrigated under this project. The total incremental cereal production would be 4.5 million tonnes and in addition 700 000 tonnes of pulses will also be produced. The net return from the whole of the project is Rs. 251 crores/ annum ($335 million/annum). The implementation of the project would result in increase in per capita income in the area to the extent of Rs. 150/annum ($20 million), about 20%. The per capita income of persons directly engaged in the project will increase by about Rs. 1400 ($187) per annum. The project by itself will contribute Rs. 486 crores or $650 million to the gross national

NET PROFIT PER HECTARE

FOR VARIOUS CROP ROTATIONS
AT VARYING WATER RATES

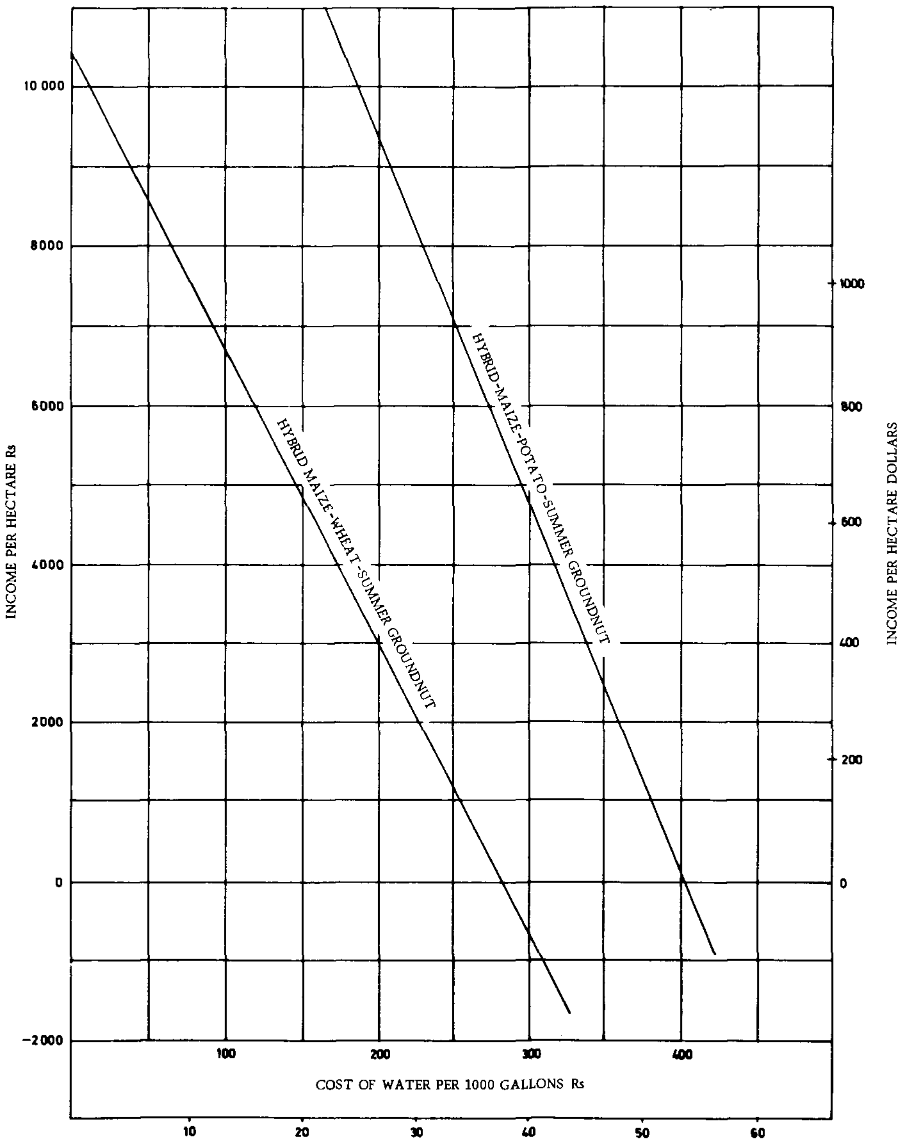

Fig. 3

product. When one considers that the most important tasks which face India are to increase per capita income and to grow sufficient food for meeting the population growth, it can be seen that the establishment of such projects has a very significant impact. Nuclear energy is crucial for implementing the scheme because this particular area is outside the break-even contour between nuclear and thermal generating stations.

A similar study has been completed of economic implications in an area of Kutch (Saurashtra) where sub-soil water is not available. The project consists of a nuclear power plant giving 1200 MWe of net salable power and attached desalination plant producing 150 MGD of water. The fertiliser plant would produce ammonium nitrate, diammonium phosphate and triple superphosphate. Also there will be an aluminium plant of capacity of 150 tonnes/day (assuming approximately 90% plant factor) or 50 000 tonnes/annum. The percentage return on investment for the power and water system alone is estimated at 6.48% and for the whole of the industrial part of the project (including the dual purpose plant) at about 11.8 per cent. Further the agricultural farm would produce 192 000/tonnes of maize, 392 000 tonnes of potato and 46 400 tonnes of groundnut. The foodgrain production alone is enough to meet the requirements of 1 million people. The investment on the whole project, excluding the agricultural farm, would be Rs. 598 crores ($798 million). Net returns from the agricultural farm will be Rs. 13.67 crores ($18.2 million) per annum. The project will contribute Rs. 220 crores ($266 million) per annum to the gross national product.

PROBLEMS OF SELECTION

A developing country generally faces many problems in the selection of the size and type of nuclear reactors to initiate a nuclear power programme in view of various limitations involving technical, economic and national considerations.

An early start on the nuclear power programme enables experience to be gained in the design, construction and operation of power reactors. The manufacture of special reactor components generally demands a very high degree of skilled workmanship. Hence, the construction of even small power reactors would provide valuable experience, and would enable building up technical manpower which is the essential requirement if a country were to embark on a nuclear power programme. In some cases siting of a nuclear power reactor in a remote area would make it possible to open up the area to general industrial development, which otherwise would not have been possible if conventional fuel sources were to be transported over a long distance.

In selecting the type of nuclear reactor that would be suitable for a developing country, many aspects such as fuel and material resources, industrial capability and national policy would have to be considered. The choice between natural uranium as against enriched uranium fuelled reactors would depend upon whether natural uranium resources are available within the country. Even if the uranium were to be imported, the availability of enriched uranium from only a limited number of supplier countries, as against the availability of natural uranium from any one of the many supplier countries, would be an important consideration. For example, a country proposing to install 5000 MWe of nuclear power may have to spend about 35 million dollars per year in foreign exchange for the purchase of enriched uranium fuel supplies, amounting to a total of over a billion dollars over the operating lives of the nuclear stations. On the other hand, if a country were to install natural uranium fuelled reactors it would utilise the indigenous uranium if available, or import natural uranium concentrates which may involve a total foreign exchange outlay of about 250 million dollars over the operating lives of the stations. Hence natural uranium fuelled reactors would perhaps be preferred in the case of a developing country.

REASONS FOR INDIA'S DECISION

Evaluation of various reactor types indicated that in view of India's limited uranium resources, natural uranium fuelled heavy water reactors would be the best choice as they could support the maximum amount of electrical generating capacity per tonne of uranium mined, taking into account both the initial fuel inventory and consumption requirements. As heavy water reactors produce the maximum amount of plutonium per tonne of uranium mined, use of plutonium to fuel the second generation fast breeder reactors would enable a much larger nuclear power programme to be sustained.

The Indian Atomic Energy Commission has, therefore, decided that though in specific cases based on technical and economic considerations enriched uranium fuelled reactors might be advantageous and may be built in India, for the overall nuclear programme of the country, only natural uranium fuelled heavy water reactors should be installed as the first generation reactors.

In the case of India's first nuclear power station at Tarapur, two BWR type reactor units of 200 MWe each using enriched uranium as fuel have been selected and are being built by International General Electric Co. For the second power station, as a result of joint studies carried out with Atomic Energy of Canada Ltd., it was decided in 1964 to construct in collaboration with AECL, a 200 MWe CANDU type unit at Rajasthan and subsequently the construction of a second 200 MWe unit has also been taken up at the same site. For the third station at Madras, it has also been decided to construct two 200 MWe reactors of the CANDU type. The entire responsibility for construction is being carried by the Power Projects Engineering Division of the Indian Atomic Energy Commission.

This decision to continue constructing CANDU type reactors has enabled systematic efforts to be directed towards developing the required indigenous skills, know-how and technology, thus permitting successive nuclear stations with increasing indigenous content. Rajasthan Unit-1 involves a foreign exchange component of about 61%, Rajasthan Unit-2 about 36% and Madras Unit-1 about 20%. It is recognised that though the capital costs of CANDU type reactors are at present relatively high, their fuelling costs are low.

ATOMIC ENERGY IN INDIA

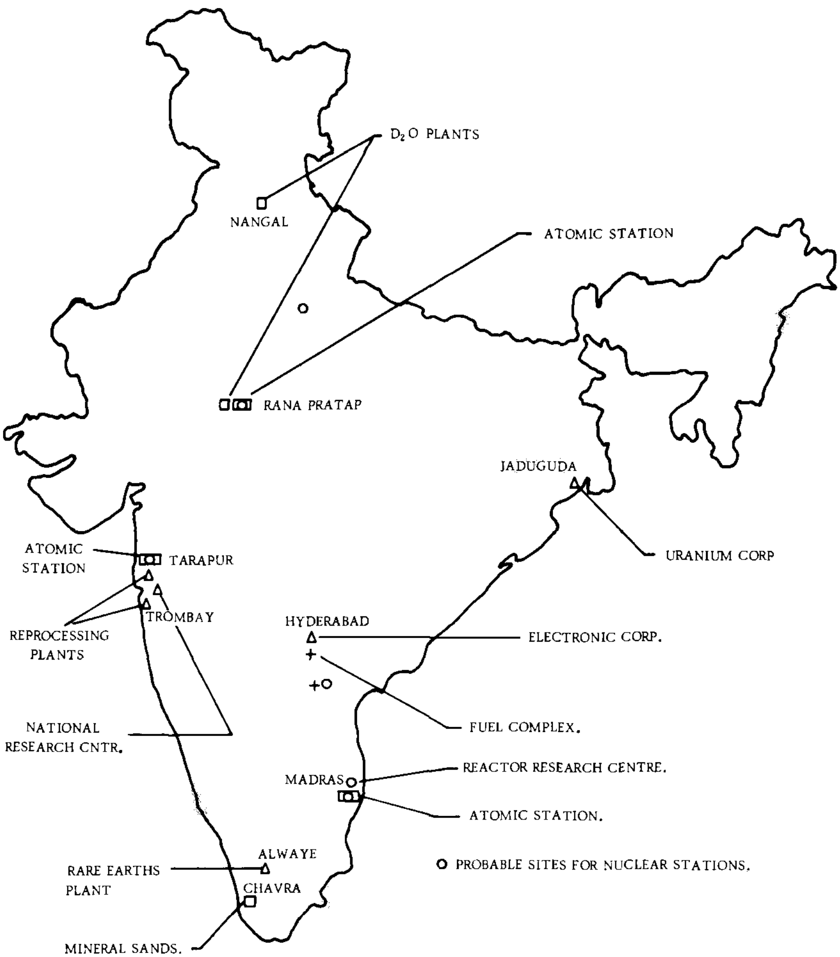

Fig. 4

Figure 4 shows the principal establishments of the Indian Atomic Energy Commission which are either commissioned or are in the process of completion. The projects are backed up by a programme of basic applied and developmental research undertaken by the Bhabha Atomic Research Centre and other establishments.

A most important developmental project relates to the establishment of a plutonium fuelled fast breeder test reactor. The presently known uranium resources in India are rather limited and could support only about 5-10 000 MWe of nuclear power based on heavy water reactors for the life times of these reactors. Whilst exploration efforts are being intensified, studies have been carried out to estimate the growth potential of fast breeder reactors based on the plutonium produced from 5000 MWe of thermal reactors. The results clearly show that a much larger nuclear power programme can be sustained by the use of bred plutonium in fast breeder reactors. The necessary development efforts have therefore been initiated in India. These are also significant for utilisation of thorium for power.

By all standards we have a formidable task to provide a new atomic power station of approximately 500 MWe capacity each year after 1972-73, using a minimum of foreign exchange, a very scarce commodity, and also providing the maximum spin off to industry.

If I were to name the most important bottle-neck in our programme today, it is of trained scientists and engineers with experience to take over independent responsibility for design and construction of sophisticated plants. Even with about 2500 scientists and engineers in the Commission's establishments, we find ourselves seriously stretched to undertake all the tasks which we can now identify for reaping a return for the investment which has been made in the last 20 years in Atomic Energy.

POWERFUL ELEMENT FOR PROGRESS

If there is a moral in the story I would summarise it as follows. Undoubtedly nuclear power projects are going to be a most powerful element in the progress of developing nations. The advantages will be great if the developing nations do not acquire them as black boxes but develop indigenous capability to the extent feasible in relation to their human, financial and industrial resources. This is hardly possible unless there is participation in serious training programmes involving all aspects of research covering fundamental sciences and technological tasks. Above all developing nations would have to consider whether they could afford to depend for their fuel resources on imported fuels. For this might result in the future to a new type of dependence of some countries on others, of rather profound significance in political and social terms. Moreover striving for self-reliance is not to be confused with self-sufficiency, for progress will depend on their ability to receive as well as to give knowledge and technology internationally, on being able to interact with mutuality with other nations. For this they will need competence and self-confidence.

For developing nations to make use of the benefits of nuclear power they need to plan imaginatively not only the low cost power units but also the power consuming complex that could provide much needed inputs to the economy. They would have to disregard the traditional pattern by which initiatives are taken independently to provide different essential national national inputs. Recognising that in this matter one plus one can be much more than two, they would need a new approach differing from the current practice which depends largely on growth curves of electrical load in the cover that internal, social, administrative and political problems are at least as important as economic and technological factors in undertaking tasks, and more difficult to solve since these do not lend themselves to meaningful outside assistance. This is precisely why they would find the task most challenging as well as rewarding. For in confronting these problems squarely in respect of precise projects which cover almost every facet of national life they would acquire new strength and purpose of even more long term significance than the project itself.

TABLE 1

AGRO-INDUSTRIAL COMPLEX - WESTERN INDO-GANGETIC REGION

INVESTMENT COSTS

Plant	*Capacity*	*Costs in crores of Rupees* Foreign Exchange	Total
Nuclear Island	1200 MWe	31.600	158.000
Electric Plant		13.400	67.000
Power Plant Total	1200 MWe	45.000	225.000
Fertilizers*	4475 Te/Day	44.911	166.283
Aluminium Plant	150 Te/Day	17.494	38.687
Total for Industrial Complex		107.405	429.970

*Ammonium Nitrate 3200 Te/Day
Diammonium Phosphate 1275 Te/Day

TABLE 2

AGRO-INDUSTRIAL COMPLEX-WESTERN INDO-GANGETIC PLAIN

OPERATING COSTS & PROFITS

Plant	Operating Costs Crores of Rupees	Revenue from Sales Crores of Rupees	Profit Crores of Rupees	% return on Investment
Power Plant	13.715	31.900	18.185	8.08
Fertilizer Plant	59.577	88.820	29.243	17.59
Aluminium Plant	14.720	27.500	12.780	33.04
Total for Industrial Complex	88.012	148.220	60.208	14.00

TABLE 3

AGRO-INDUSTRIAL COMPLEX

Indo-Gangetic Plain

AGRICULTURAL ECONOMICS OF THE PROJECT

Area to be irrigated (hectares)	720 000
Number of tubewells	36 000
Products (additional) in tonnes	
Cereal	4.5 million
Pulses	0.7 million
Net return of the Project	Rs 2512 million
Fertilizer requirements (in tonnes)	
Nitrogen as fixed N_2	166 000
P_2O_5	83 000
Total investment on drilling	Rs 432 million
Net return per hectare	Rs 3767
At 200 kg annum per head the additional cereals produced from the project will be able to meet the food requirement of 22.5 million people.	
Population of the area covered under the project	23 621 716
Increase in per capita income in the area due to the project (Agricultural part only)	Rs 150.00 per annum
Average per capita income (additional) of the population directly involved in the project	Rs 1404.00 per annum

In a laboratory at the Democritos nuclear research centre, Athens, A. Hastie, an IAEA technical assistance expert in plant biology supervises work on fungicide research. He is also arranging a course for graduate students. (Photo: IAEA/Moir)